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Practical Ignition Problems Related to Intrinsic Safety in Mine Equipment

Four Short-Term Studies

By E. L. Litchfield, T. A. Kubala, T. Schellinger, F. J. Perzak, and D. Burgess

UNITED STATES DEPARTMENT OF THE INTERIOR

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This report describes previously unreported studies by Elton Litchfield whose death in June 1978 deprived the Bureau of Mines of a keen intellect and a long-standing devotion to mine safety problems.

PRACTICAL IGNITION PROBLEMS RELATED TO INTRINSIC SAFETY IN MINE EQUIPMENT

Four Short-Term Studies

by

E. L. Litchfield,[1] T. A. Kubala,[2] T. Schellinger,[3] F. J. Perzak,[4] and D. Burgess[5]

ABSTRACT

Four short-term studies of practical ignition problems were undertaken and completed during the course of the Bureau of Mines project "Development of Specifications for Intrinsically Safe Equipment." Conclusions were as follows: (1) the most easily ignitible mixture of propane-air in a PTB break flash apparatus is approximately 5.2 percent propane; (2) miniature lamp bulbs to be used in intrinsically safe circuits are about as incendive to coal dust-air as to methane-air and should be tested in gas mixtures containing about 7.0 to 7.5 percent methane; (3) the sodium amalgam contained in high-pressure sodium lamps does not present an ignition hazard for coal dust or methane, where the lamps contain no more than 30 milligrams of amalgam; (4) the maximum allowable surface temperature of permissible electrical enclosures should remain at 150° C despite efforts by industry groups to raise the value to 200° C.

INTRODUCTION

In the early 1970's, the concept of intrinsically safe electrical equipment had been widely accepted and incorporated into codes covering electrical installations, including Bureau of Mines Schedule 2G. At that time, the Approval and Testing Group of the Pittsburgh Technical Support Center contemplated revision of Schedule 2G and requested research on the design guidelines for intrinsic safety, particularly on the performance of "break flash" testing apparatus. This research was conducted both in house and through contract with the Denver Research Institute. The principal investigator and contract monitor of the program was Elton Litchfield of the Fire and Explosion Prevention group.

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[1] Supervisory research physicist (deceased).
[2] Physicist.
[3] Engineering technician.
[4] Research chemist.
[5] Formerly Supervisor, Fire and Explosion Research (retired).
All authors were or are with the Pittsburgh Research Center, Bureau of Mines, Pittsburgh, Pa.

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Before his untimely death in 1978, Mr. Litchfield had accomplished many of the objectives of the program and had contributed to a draft of revised Mine Safety and Health Administration (MSHA) regulations which are now in the approval process. However, his death left unreported the results of several short-term investigations which relate to peripheral problems in intrinsic safety, rather than to the main issue of circuit design. Brief statements of the problems follow:

1. Most easily ignitible mixture of propane-air.--When an electrical circuit is tested for intrinsic safety by break flash apparatus, it is desirable that approval be based on some factor of safety. It is not reasonable to achieve this factor of safety by altering in any way the parameters of the circuit. One proposal is to test the circuit in propane-air, which is somewhat more easily ignited than methane-air. But while the most easily ignited (by break flash) methane-air mixture is about 8.3 percent methane, there has been some confusion as to the appropriate propane-air mixture.

2. Miniature lamp bulbs for intrinsically safe circuits.--The tiny light bulbs that are used in instrument lighting are tested for incendivity to methane-air. It is not to be assumed that the appropriate methane-air mixture is 8.3 percent methane or that coal dust-air is necessarily less ignitible by a lamp filament than is methane-air.

3. Incendivity of broken high-pressure lamps containing sodium amalgam.--Although strictly speaking this matter is not related to intrinsic safety, it is a practical problem of ignition on which help was requested during the project. It was known that discarded low-pressure lamps, containing up to a gram of elemental sodium, are a real safety hazard. However, the high-pressure lamps in question contain only about 8 milligrams of sodium (Na) in the form of a mercury (Hg) amalgam, Na_3Hg.

4. Maximum allowable surface temperature of electrical enclosures.--The traditional value has been 150° C, based on British and U.S. studies in the 1950's. However, discussion had begun (for example, within a National Fire Protection Association committee) as to whether the allowable temperature should be raised to 200° C. At the same time, Bureau personnel had some feeling that 150° C was, if anything, too high.

Each of these investigations produced useful data which have been orally reported to the individuals (in MSHA) who were immediately concerned. The purpose of this report is to make permanent record of the findings.

OPTIMUM METHANE-AIR AND PROPANE-AIR MIXTURES FOR USE IN INTRINSIC SAFETY TESTING

Background

In the 1950's there were two important rationalizations concerning optimum methane-air and propane-air mixtures that have been accepted without any known dissent during the following two decades.

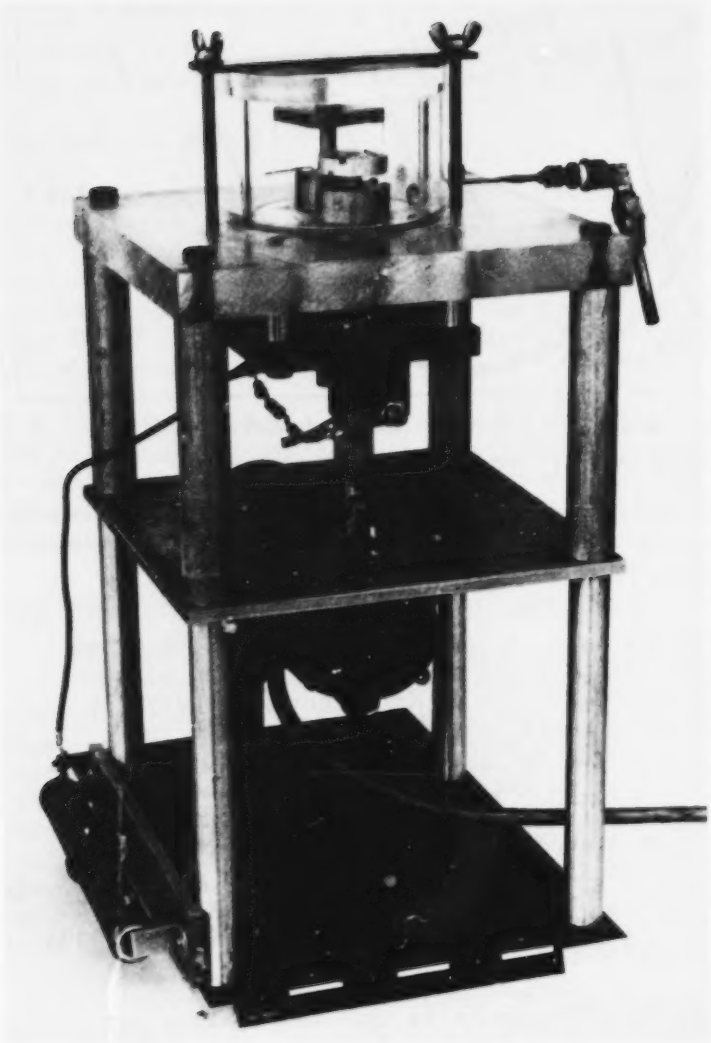

FIGURE 1. - Physikalische-Technische-Bundesanstalt (PTB) break flash testing apparatus, showing rotating cadmium (slotted) disk and tungsten wire within chamber of flammable methane-air mixture.

The first rationalization was by E. Litchfield,[6] who was concerned with ignition of gas mixtures by electrostatic spark and by "break spark." In electrostatic spark ignition, the significant measured quantity is minimum ignition energy as calculated from circuit capacitance and breakdown voltage; in break sparks, the measurable quantity is minimum igniting current. The energy required for ignition by break spark (by the apparatus shown in figure 1) is typically much larger than that needed by electrostatic spark. Litchfield postulated that the two ignition processes were identical except for electrode spacing at the time of energy release; with electrostatic sparks of minimum energy, the electrodes are prespaced at a separation equal to or greater than the quenching distance for the gas mixture (thus, little or no energy is lost from the ignition kernel to the electrodes); in break sparks, the experimenter has no control over the separation of the conductor, but he does know that the gap is small and that much of the kernel's energy is absorbed by the separating wire. According to this concept, the most easily ignited gas mixture should be independent of the two modes of ignition.

[6] Litchfield, E. L., and M. V. Blanc. Recent Developments in Spark Ignitions. BuMines RI 5461, 1959, 9 pp.

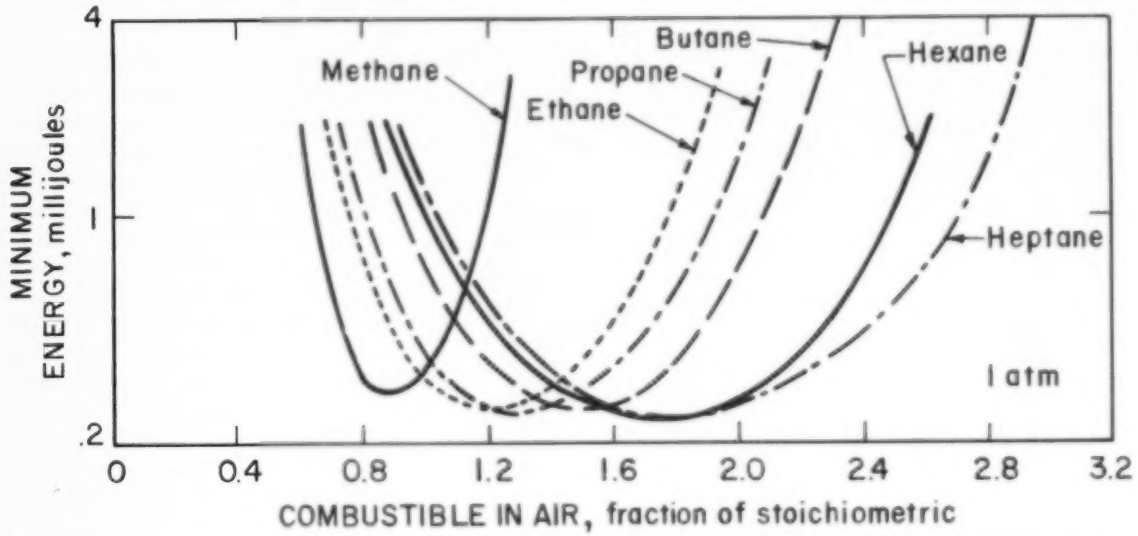

FIGURE 2. - Minimum ignition energies of hydrocarbon-air mixtures in relation to stoichiometric percentage in air. From Lewis and Von Elbe, Combustion, Flames and Explosions of Gases, Academic Press, 1951.

The second rationalization was by D. B. Spalding,[7] who was concerned with the shifting stoichiometric ratio of the most easily ignited mixtures of hydrocarbon-air as given in figure 2. The minimum ignition energy is found at 0.9 stoichiometric in methane-air, at 1.8 stoichiometric in heptane-air, and at intermediate values for the intermediate hydrocarbons. The optimum stoichiometries are close to the corresponding values of $(D_o/D_f)^{1/2}$, where D_f and D_o are the diffusivities of fuel and oxygen molecules, respectively. From this he argued that the actual fuel-oxygen ratio in the developing flame kernal is stoichiometric at all optimum gross concentrations of hydrocarbon in air. This concept was found useful by Furno[8] to systematize the lean and rich limits of flammability of hydrocarbons for upward and downward flame propagation.

The obvious consequence of these arguments is that the optimum gas concentrations for ignition by break flash or break spark apparatus should be 0.9, 1.2, 1.3, 1.5, 1.7, 1.8 stoichiometric for methane-, ethane-, propane-, butane-, hexane-, heptane-air, respectively. Unfortunately, the minimum currents for ignition of propane-air by the Physikalische-Technische-Bundesanstalt (PTB) break flash were seemingly encountered with very rich gas mixtures, close to the upper explosive limit.[9] Therefore, it was deemed

[7] Spalding, D. B. Some Fundamentals of Combustion. Academic Press, 1955, p. 175.
[8] Furno, A. L., E. B. Cook, J. M. Kuchta, and D. S. Burgess. Some Observations on Near-Limit Flames. Proc. 13th Symposium on Combustion, 1971, pp. 593-599.
[9] Zborovszky, S. Denver Research Institute. Private Communications. Available for consultation at Denver, Colo.

advisable to make a careful study of minimum igniting currents over the full range of flammable concentrations for methane-air and propane-air.

Experimental Work

The PTB apparatus employed was constructed locally from drawings in Underwriters' Laboratories Standard 913 "Intrinsically Safe Electrical Circuits and Apparatus" (1975 edition). The "break flash" was between tungsten wire and a grooved cadmium disk. Current was measured with the 0.020-centimeter-diameter tungsten wire and cadmium disk in contact at rest, and then the electrodes were put into rotation. Circuit inductance was set at 100 millihenries.

Gas concentrations were achieved by adjusting mass flow rates of fuel and air through mass flowmeters, ultimately calibrated by water displacement. In addition samples of the gas mixtures were submitted periodically to gas chromatographic analysis. Methane (CP) and propane (CP) were taken from commercial high-pressure cylinders.

Results

Figures 3 and 4 show igniting currents at 24 volts for methane-air mixtures and propane-air mixtures, respectively. Open circles represent nonignition, and crosses represent ignition. Also shown for easy comparison (triangles) are the minimum ignition energies from which the curves of figure 2 were constructed.[10] The minimum energy curves are remarkably symmetrical, permitting close identification of the optimum gas concentrations for ignition. These concentrations are about 8.7 percent for methane-air and 5.2 percent for propane-air. The curves for minimum igniting current are not quite so clean cut. The minimum for propane-air is at or near 5.2 percent, in good agreement with the energy curve; however, the minimum for methane-air is not so well defined and could be anywhere from 8.0 to 8.7 percent methane.

The minimum igniting currents in figures 3 and 4 are 96 milliamp for methane-air and 85 milliamp for propane-air. This ratio corresponds well to minimum ignition energies of 0.28 millijoule for methane-air and 0.25 millijoule for propane-air. Thus the safety factor achieved by using propane-air instead of methane-air is about 1.1.

Conclusions

The experimental evidence suggests that the same ignition process occurs in the PTB apparatus as in the electrostatic spark ignition bomb. Optimum gas concentrations shift in the same direction from stoichiometric, and methane-air is slightly more difficult to ignite in each apparatus than propane-air.

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[10] Blanc, M. V., P. G. Guest, G. Von Elbe, and B. Lewis. Ignition of Explosive Gas Mixtures by Electric Sparks. Proc. 3d Symposium on Combustion, Flame and Explosion Phenomena. Williams & Wilkins Co., Baltimore, Md., 1949, pp. 363-367.

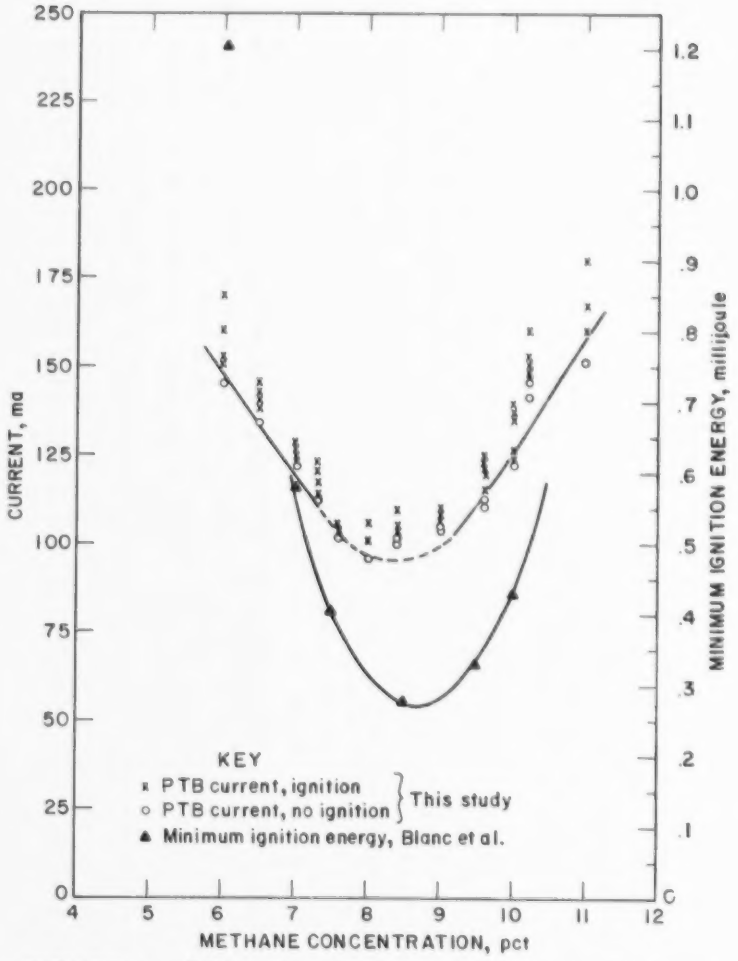

FIGURE 3. - Effect of methane concentration on minimum igniting current and on minimum ignition energy for methane-air mixtures.

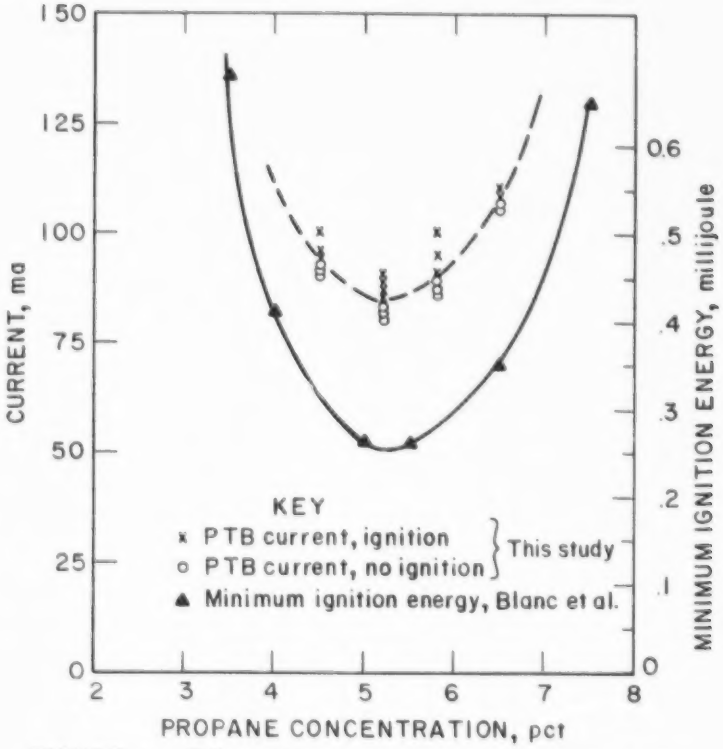

FIGURE 4. - Effect of propane concentration on minimum igniting current and on minimum ignition energy for propane-air mixtures.

In the PTB apparatus one should expect optimum gas concentrations of heavy hydrocarbons to follow the trend presented in figure 2.

IGNITION OF METHANE-AIR AND COAL DUST-AIR MIXTURES BY MINIATURE LAMP BULB FILAMENTS

Background

Small portable instruments carried into coal mines by miners and inspectors and permanently installed monitoring devices contain minature lamp bulbs as indicator lights. If the glass shell of the bulb is accidentally broken while the filament is intact, the energized filament is possibly incendive to methane-air mixtures or coal dust-air mixtures. When the bulb is small enough (low wattage, fine filament, low thermal inertia) that no ignitions are observed in the laboratory, the bulb can be approved for incorporation into an intrinsically safe circuit without added safety features.

Standard procedure by the Approval and Certification Center of MSHA is to smash the glass envelope in an ambient flammable atmosphere while the filament is energized at a voltage indicated by the lamp's specifications. The filament must, of course, remain intact during this process. The procedure is conducted 30 times; if no ignitions occur, the bulb is approved. The test is awkward in several respects: it is sometimes difficult to break the glass without simultaneously damaging the filament; it is particularly difficult to synchronize this operation with the dispersal of a coal dust-air mixture; and it is not clear that the standard (most ignitible) gas mixture should be the 8.3 percent methane in air that is used in the PTB breakflash apparatus.

It was requested by MSHA that some study of this problem be included in the in-house project on intrinsic safety.

Experimental Work

Various schemes were attempted for removing the glass envelope of the bulb without damaging the filament. All were finally discarded in the interest of test repeatability. In all experiments reported, the glass was first cracked and removed before the bulb was inserted into its base in the test vessel.

The test chamber for methane-air ignitions is shown in figure 5. It is a cast acrylic tube, 6.4 millimeters in wall thickness and 70 millimeters in ID by 102 millimeters high. Pressure relief is provided by a masking tape diaphragm in the bottom plate. Air and methane were taken from commercial cylinders and metered through calibrated flowrators. Gas concentrations were achieved by adjusting mass flow rates of fuel and air through mass flowmeters; the flow was twice divided and remixed as opposed jets. Samples were taken periodically for gas chromatography. The lamp filaments were energized by a regulated power supply preset to the desired voltage and manually switched on to start the test.

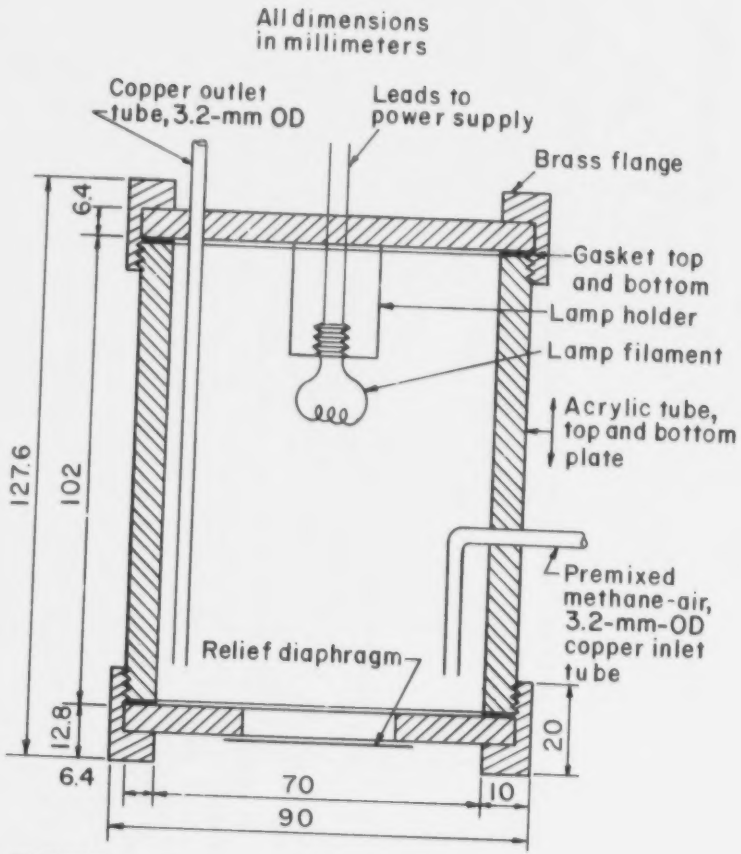

FIGURE 5. - Test vessel for methane-air ignition by miniature lamp bulb filaments.

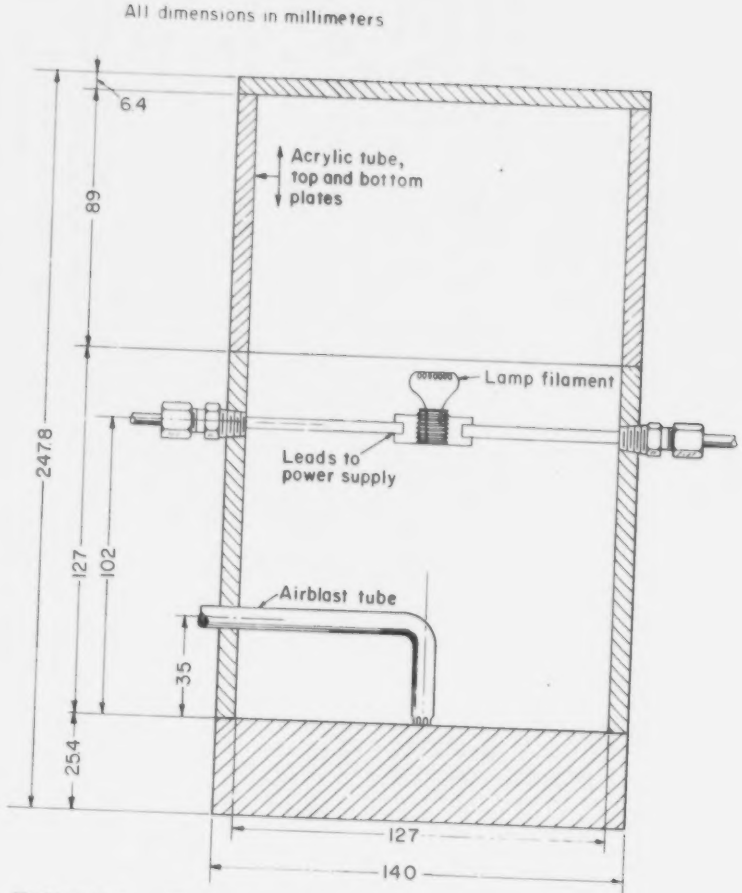

FIGURE 6. - Test vessel for coal dust ignition by miniature lamp bulb filaments.

The test chamber for coal dust-air ignitions (fig. 6) was a cylindrical vessel, 127 millimeters in ID by 216 millimeters high (2.7 liters), that had been used to achieve the lowest spark energies for dust cloud ignition. The coal dust (3 grams) was dispersed by a 1 liter blast of air from a 15-psig storage reservoir; the dust was initially piled around the 4.8-millimeter ID air injection tube, the open end of which was in contact with the bottom plate of the vessel; the eight grooves in the end of the tube were significant to the mode of dust dispersion; the 1 liter of added air was vented through the loose-fitting top plate of the chamber so that tests were conducted at atmospheric pressure. The lamp filament was quickly energized manually after the initiation of the air blast.

Results

Table 1 is a list of the 32 lamps tested, in descending order of design wattage. The three lamps in the top group (3 watts or more) all ignited methane-air mixtures or coal dust-air mixtures at design voltage. About half of the intermediate group (1.79 to 0.95 watt) were incendive at design voltage. None of the lamps in the third group (0.74 to 0.08 watt) were incedive at design voltage. The lamp numbers in table 1 are trade numbers recorded with the American National Standards Institute and are uniform throughout the industry.

TABLE 1. - Ignition of methane-air mixtures and coal dust-air mixtures by lamp bulb filament

Lamp No.	Design watts	Design volts	Methane-air mixtures		Coal dust-air mixtures	
			Ignition, volts	No ignition, volts	Ignition, volts	No ignition, volts
6S6	6	120.0	NT	NT	75.0	70.
T4 1/2	4	120.0	120.0	NT	NT	NT
3S 6/5	3	120.0	NT	NT	120.0	100.0
PR-3	1.79	3.57	4.0	3.6	4.0	3.0
1813	1.73	14.4	14.4	NT	NT	NT
46	1.58	6.3	6.3	NT	NT	NT
1408	1.30	10.0	13.0	12.0	NT	NT
378	1.26	6.3	12.0	10.0	NT	NT
43	1.25	2.5	2.6	NT	NT	NT
PR-2	1.19	2.38	2.4	2.0	NT	NT
28ESB	1.12	28.0	28.0	NT	24.0	22.0
382	1.12	14.0	23.0	22.0	NT	NT
387	1.12	28.0	[1]25.0	40.0	NT	NT
388	1.12	28.0	[1]25.0	40.0	NT	NT
399	1.12	28.0	NT	40.0	NT	NT
327	1.12	28.0	NT	40.0	NT	NT
13	1.11	3.7	3.3	3.1	3.7	NT
47	.95	6.3	6.0	5.7	NT	NT
PR-6	.74	2.47	4.0	3.5	NT	NT
14	.74	2.47	3.3	3.0	NT	NT
233	.63	2.33	2.5	2.3	NT	NT
PR-4	.63	2.33	4.3	4.0	NT	NT
222	.56	2.25	5.0	4.5	NT	NT
1775	.47	6.3	9.0	8.5	NT	NT
377	.45	6.0	10.0	9.0	NT	NT
1850	.45	5.0	12.0	10.0	NT	NT
7683	.30	5.0	NT	10.0	NT	NT
380	.25	6.3	38.0	35.0	NT	NT
345	.24	6.0	NT	10.0	NT	NT
338	.16	2.7	6.0	5.0	NT	NT
49	.12	2.0	3.5	3.3	NT	NT
331	.08	1.35	6.0	5.0	5.0	NT

NT Not tested

[1]Filament support wires removed.

Four lamps were tested both in methane-air and in coal dust-air. In two of the four cases, ignition was attained at lower applied voltage in coal dust-air than in methane air. Unfortunately, nothing can be stated as to the concentration of coal dust which is so easily ignitible. The gross nominal concentration in the test vessel was about 1.1 grams of coal per liter of air, or roughly 10 times stoichiometric for combustion to CO_2 and H_2O. However, the suspension provided by the airblast was probably not uniform. It is consistent with other experimental work that very rich coal-air mixtures are more

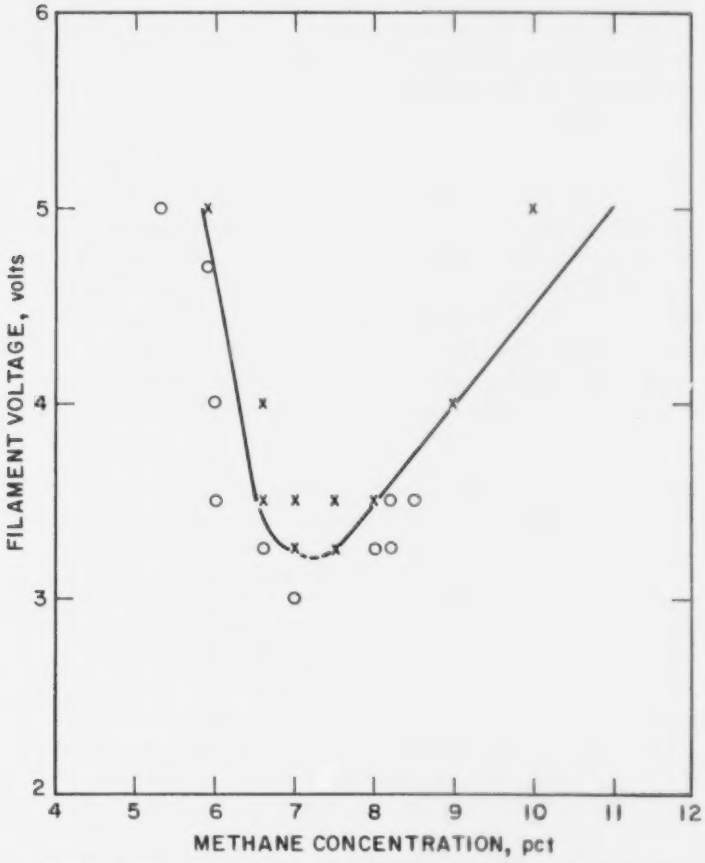

FIGURE 7. - Ignitability of methane-air as a function of applied filament voltage lamp bulb 13. X = ignition, O = no ignition.

readily ignitible than the 0.2- to 0.3-grams-per-liter coal dust-air that produces heavy explosions in the Bureau's Experimental Mine.

Lamp 13, of intermediate wattage, was used extensively to study ignitability as a function of methane-air concentration. Fifty-one trials were made using lamps of this specification from three manufacturers. No conclusion is offered as to the importance of the manufacturer source of the lamp. The results are plotted in figure 7.

The gas mixture that is most easily ignitible by lamp 13 is clearly in the concentration range of 7.0 to 7.5 percent methane. However, ignitions were obtained over the concentration range 6.6 to 8.0 percent when the lamp filament was energized at 3.5 volts. Design voltage is 3.7 volts. By applying a higher voltage (5 volts), ignitions were achieved over the range of 5.9 to 10.0 percent methane.

No guarantee is possible that 7.0 to 7.5 percent methane is the most easily ignited mixture for all lamps. We subscribe to the present consensus that ignition sources may be categorized by their localization of energy in space and time. Thus, the electrostatic spark is a good approximation to a true point energy source; ignition or nonignition is determined purely by the energy release (not, for example, by temperature), and the most easily ignited methane-air mixture is about 8.7 percent methane (fig. 3).

At the other extreme, ignition by a large laminar jet of hot gas is controlled solely by the temperature of the ignition source, since the size and

total energy input of the source are large. In this case, the most easily ignited methane-air mixture is at the lower flammable limit, 5 percent methane.[11]

All practical sources of ignition are intermediate between these extremes, and the optimum mixture for test purposes depends on the localization of the energy source in space and time. Thus, it should not be surprising if the tiniest lamp bulbs are most incendive to methane-air mixtures containing slightly more than 7.5 percent methane, or that the largest lamps may be most incendive at concentrations below 7.0 percent methane.

It is particularly important to point out that all of the above discussion pertains specifically to methane mixtures. With heavier hydrocarbons one should expect ignitions to be more readily attained on the rich side of stoichiometric.

Table 1 should not be interpreted to mean that any lamp of lower than 0.74 watt should be intrinsically safe. There are design factors that have not be investigated here. Thus, lamps 387 and 388 were not incendive at 40 volts (design voltage 28 volts) but were incendive at 25 volts when a support wire was removed from the filament. Also, the MSHA approval test, in which the glass envelope is broken while the lamp is energized, may well represent a more severe test than the procedure used here.

Conclusions

There is a wide selection of minature lamp bulbs that should be nonincendive in the event of breakage within an ambient methane-air mixture. Such bulbs should be tested for Approval and Certification using a gas mixture that is considerably more lean (about 7 to 7.5 percent methane) than the standard 8.3 percent mixture used with the PTB break flash machine.

It cannot be assumed that coal dust-air is any less susceptible to ignition than is methane-air.

NONINCENDIVITY OF BROKEN HIGH-PRESSURE LAMPS CONTAINING SODIUM AMALGAM

Background

The concern that led to this study was that used high-pressure lamps are sometimes discarded in subsequently sealed gob areas. The lamps are then subject to breakage by roof falls while in contact with coal dust and in an atmosphere that may contain methane. Cold (that is, not in use) low-pressure sodium (Na) lamps have been shown to ignite methane-air when broken[12] and do represent a hazard. However, these low-pressure lamps contain up to 1 gram of sodium metal, which is highly reactive with air and water. The high-pressure lamps studied here contain only about 8 milligrams of sodium, which is bonded strongly as an amalgam (Na_3Hg) and therefore is less reactive.

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[11] Vanpée, M., and A. E. Bruszak. The Ignition of Combustion Mixtures by Laminar Jets of Hot Gases. BuMines RI 6293, 1963, 84 pp.

[12] Schwartz, M. (Mine Enforcement and Safety Administration.) Letter dated January 17, 1977; available for consultation at Pittsburgh Research Center, Bureau of Mines, Pittsburgh, Pa.

The work was performed using prepared 30-milligram sodium amalgam pellets containing 26±3 weight-percent sodium. The typical high-pressure lamp has the amalgam sealed into a gastight polycrystalline alumina arc tube 0.5 to 0.8 centimeter in ID by 4 to 11 centimeters long; the amalgam is presumably distributed on the inside surface of the tube. We think that using the amalgam in pellet form should constitute a conservative test.

Experimental Work

Small pellets of the amalgam were prepared in an argon-inerted glove box in the following manner. A small piece of sodium metal was cleaned and weighed into a small test tube. The calculated amount of mercury to make Na_3Hg was added to give the desired composition. The test tube was heated with a small soldering gun to liquefy the solution, until it could be stirred with a glass rod. The test tube containing the weighed pellet was cooled and then sealed with beeswax until use.

In some cases, the prepared pellet was placed directly on a dimpled stainless steel planchet dish and was lightly covered with moist coal dust; in other tests, it rested on a coal dust bed on top of the dish. The dish containing the sample was placed inside a small rectangular plastic box, 7.8 centimeters on the side by 10 centimeters high, through which a 7.7-volume-percent methane-air mixture flowed continuously at about 2 liters per minute for about 1 minute. A fine-tipped eye dropper syringe was inserted through a rubber-stoppered hole in the side of the box, and the top was lightly covered with a sheet of paper as a blowoff diaphragm. During tests, a few drops of water were judiciously added to the dimpled area to allow contact with the pellet-coal dust mixture.

Results

Twenty different 30±3-milligram amalgam pellets containing about 8 milligrams of sodium (26 weight-percent Na) were tested in an attempt to ignite the methane-air gaseous mixture; all were unsuccessful. The tests using a through-200-mesh Pittsburgh seam coal dust showed one sparkler; it did not, however, ignite the gaseous mixture.

The use of pure 30-milligram sodium pellets in this same manner resulted in some sparklers and no ignitions. Larger pellets, 50 to 100 milligrams of sodium, did ignite the methane-air mixtures with difficulty. The water reacted to produce steam vapor and incandescent sparklers, which were violently ejected from the coal mass. The sodium raction with wet coal dust seemed to be enhanced over that for sodium and water without coal dust. No methane-air ignitions were observed with dry coal dust alone with sodium.

Conclusions

The breakage of low-pressure lamps is hazardous if the weight of pure sodium metal exceeds 30 milligrams. But since 30 milligrams of pure sodium is seemingly nonincendive with methane-air, the hazards of 8 milligrams of sodium in an amalgam seem remote.

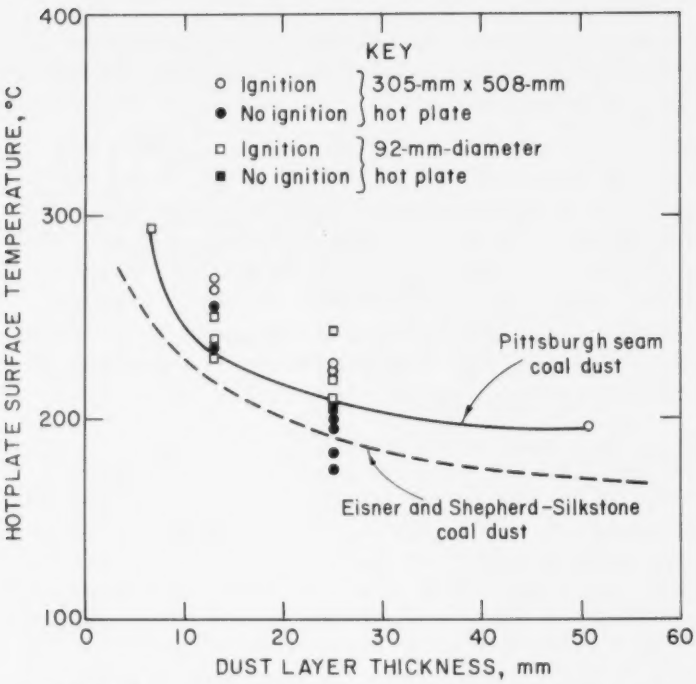

FIGURE 8. - Minimum ignition temperature of coal dust on heated surfaces.

MAXIMUM ALLOWABLE SURFACE TEMPERATURE OF PERMISSIBLE ELECTRICAL ENCLOSURES

Background

Section 18.23 of Title 30 of the Code of Federal Regulations states that "the temperature of the external surfaces of mechanical or electrical components shall not exceed 150° C (302° F) under normal operating conditions." This 150° C limit surely originated from Bureau of Mines measurements,[13] but the data usually cited to support it are the measurements of Eisner and Shepherd[14] which are reproduced in figure 8. The curves shows that surface temperatures below 200° C are sufficient to ignite Silkstone seam coal dust if the depth of the collected dust exceeds 18 millimeters. The lowest surface ignition temperature found by Eisner and Shepherd was 168° C for a dust layer thickness of 60 millimeters. If the maximum temperature of 150° C seems unnecessarily restrictive, then the key words are "under normal operating conditions." It is well recognized that a motor, for example, may run considerably hotter than normal under transient overload conditions. Thus, the 150° C restriction provides a 50° C margin of safety for abnormal conditions if one supposes that the maximum thickness of dust layer is likely to be 18 millimeters.

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[13]Dorsett, H. G., Jr., J. Nagy, M. Jacobson, and R. P. Williams. Laboratory Equipment and Test Procedures for Evaluating Explosibility of Dusts. BuMines RI 5624, 1960, 21 pp.

Nagy, J., H. G. Dorsett, Jr., and A. Cooper. Explosibility of Carbonaceous Dusts. BuMines RI 6597, 1965, 30 pp.

[14]Eisner, H. S., and W. C. F. Shepherd. Recent Research on Mine Fires. 32d Annual Report on Safety in Mines Research SMRE, 1954, p. 1063.

Cited in Palmer, K. N., and P. S. Tomkin. The Ignition of Dust Layers on a Hot Surface. Combustion and Flame, v. 1, No. 1, 1957, p. 17.

In fiscal year 1977, the Approval and Certification Center requested that Litchfield contribute to a draft of revised intrinsic safety requirements, which included a section on thermal ignition. There were two opposing forces at work at that time:

1. The National Electrical Code (NEC) was under revision to permit surface temperatures of equipment in Class II, Group F areas (which includes coal dust) to reach 200° C. The old NEC figure was 165° C, and the revision was made for consistency with Underwriters' Laboratories and American National Standards Institute standards.

2. The Fires and Explosions personnel of the Bureau of Mines were intensely preoccupied with problems introduced by western coals. Many of these subbituminous coals are subject to self-heating and spontaneous combustion. It was known, for example, that such coals go to ignition at temperatures of 110° to 120° C in a modified American Society for Testing and Materials (ASTM) D2155 test, while eastern coals typically require temperatures of 130° to 140° C. Thus, the present project was begun with the feeling that 150° C might be too high a figure for intrinsic safety with western coals.

Experimental Work

It was assumed that the coal dust in question would be "float" dust, which is nominally 80 percent through a 200 mesh screen. Three materials were chosen for testing:

1. A bituminous Pittsburgh seam pulverized coal, 95 percent through 200 mesh, 38 micrometer average particle diameter, 38 percent volatiles. This is the same dust but of somwhat finer particle size than is used in Experimental Mine explosion tests.

2. A western subbituminous coal from the Sarpy Creek mine, Stray No. 2 coalbed, Big Horn, Mont., 85 percent through 200 mesh, 33.5 percent volatiles.

3. Oil shales, pulverized and classified to the same nominal particle diameter, in three grades: 48, 25, and 19 gallons of oil per ton.

Two commercial hotplates were used to provide controlled surface temperatures. A Lindberg H-2 hotplate (115 volts, 2600 watts, working temperature 78° to 510° C) provided a large surface, 305 millimeters wide by 508 millimeters long, in heavy steel, metallized to resist corrosion. Seven thermocouples were distributed in contact with this surface, partly to eliminate questions of horizontal temperature gradient but mainly to monitor the progress of the smoldering combustion of the coal. A smaller hotplate (92-millimeter diameter, 325 watts, working temperature to 370° C) provided quicker attainment of steady surface temperature. Its top plate was of cast aluminum.

The coal dust was poured into a form on the hotplate, the top surface of the layer was smoothed with a straight edge, and the form was removed, leaving the edges of the pile with approximately a 60° slope. One thermocouple was

inserted to a depth of 1 millimeter into the top surface of the coal dust, and two others to greater depth depending on the dust layer thickness. Thermocouples were made from 43-, 28-, and 20-gage copper constantan wires.

Results

The first observation is the very long duration of heating that is required to obtain ignition at temperatures approaching those of Eisner and Shepherd. This is illustrated in figure 9; the large hotplate was maintained at temperatures exceeding 197° C for 6 hours before an upturn of temperature was observed near the coal dust-air interface. Presumably a slightly lower ignition temperature might have been attained by even more extended duration of heating.

We chose to assume that exposure for longer than one shift would be unreasonable. On this basis, figure 8 shows the results of 10 trials to establish a minimum surface temperature for ignition of a 25.4-millimeter-thick pile of Pittsburgh seam dust. Five failures are recorded at 201° C and below; five ignitions are recorded at 209° C and above. Work was discontinued on Pittsburgh seam coal with high confidence that the Eisner and Shepherd data are sufficiently conservative and that there was no further need to use the large hotplate, which required inconveniently large quantities of classified coal.

Because of the shortage of sample, Sarpy Creek bituminous coal was tested only twice on the small hotplate, using 12.7-millimeter-thick layers for comparison with Pittsburgh coal. The plate temperatures were 247° C and 235° C, compared with 233° C for Pittsburgh coal. The only observed difference between these samples was that the Pittsburgh coal smoldered quietly, opening cracks which glowed red, and occasionally displaying a pale blue flame; the Sarpy Creek coal emitted hot glowing sparks. Either combustion process would probably have ignited ambient methane-air.

Oil shale assaying at 48, 25, and 19 gallons per ton ignited at 200°, 240°, and 300° C, respectively, all in 51-millimeter-thick layers on the large hotplate. The first outward sign of reaction, using the high-assay material, was a light smoke accompanied by the appearance of a dark spot on the edge of the layer. Two and a half hours later a heavy smoke bellowed from cracks in the surface; when a lighted match was held 7 inches from the surface, flame flashed back to the pile and was difficult to extinguish. The experiment points out that fire hazards are different in kind with oil shale and that test methods much be chosen accordingly. Figure 10 shows the temperature histories for the 48-gallons-per-ton oil shale.

Conclusions

For immediate purposes a draft of intrinsic safety regulations, the decision was made to retain the limit surface temperature of 150° C. No consideration should be given to raising the permissible surface temperature to 200° C, and the scanty experience with western coal does not dictate that the present value should be lowered.

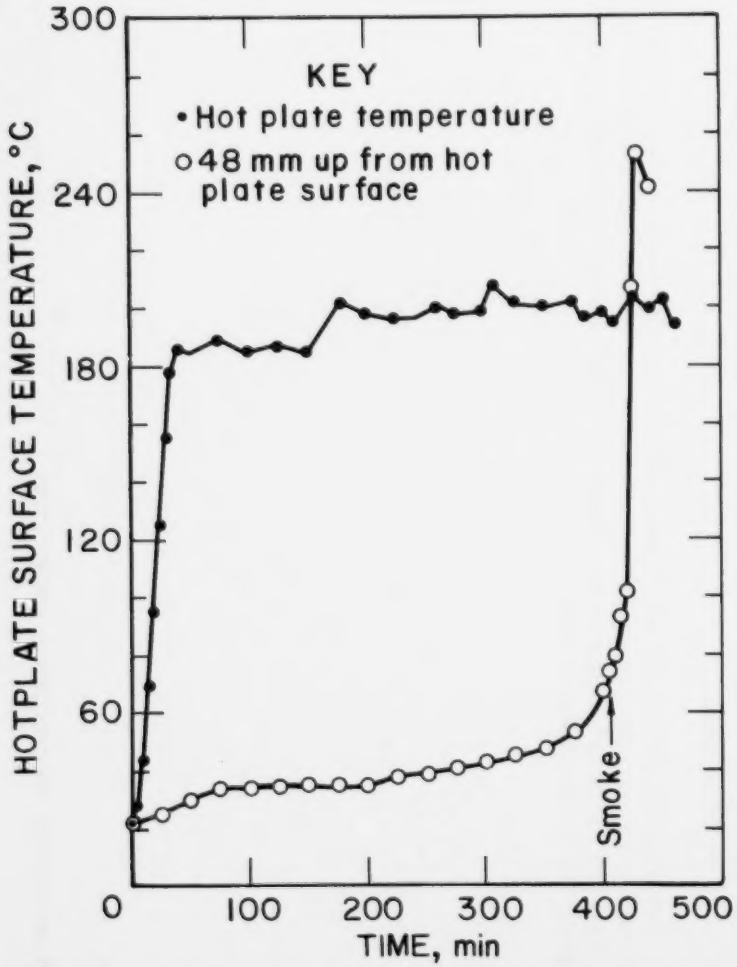

FIGURE 9. - Temperature history of a 50-mm-thick coal dust layer on hotplate.

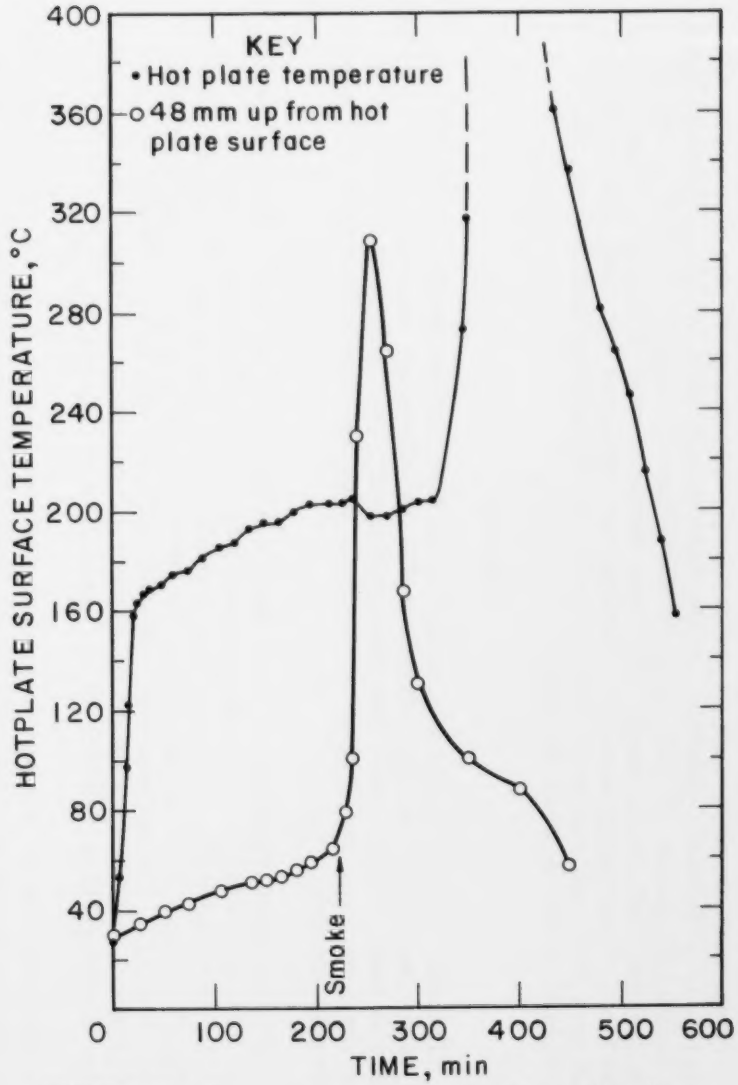

FIGURE 10. - Temperature history of a 50-mm-thick layer of 48-gal/ton oil shale on hotplate.

Since work on this task is continuing, discussion of the mechanism of ignition is deferred. However, it is fair to say that we are concerned about the quiescent nature of this test in which heat is conducted slowly upward from the hotplate while oxygen diffuses downward with difficulty from the air interface. Continuing work will incorporate measures to speed the diffusion of oxygen into the hot coal; for example, by mechanical disturbance and by controlled particle size of coal.

SUMMARY

The most easily ignited mixture of methane (or propane) in air has about the same composition using either the PTB apparatus or the electrostatic spark ignition bomb. This result had been postulated by Litchfield and suggests that the same ignition processes occur in both the break flash and the electrostatic spark.

The hot-wire ignition of coal dust-air mixtures by small lamp filaments is at least as easy as with methane-air mixtures. Some small lamps can be used in intrinsically safe circuits provided they are operated within their designed voltage. It is important to specify that the given results (table 1) are specific for methane-air and coal dust-air mixtures. Small changes in filament construction, such as reducing the number of support wires, can change a nonignition results to an ignition for some bulbs.

The breakage of discarded low-pressure sodium vapor lamps containing more than 30 milligrams of pure sodium can ignite methane-air mixtures. Sodium amalgams in high-pressure lamps containing less than 30 milligrams of sodium appear to be innocuous.

The present hot surface temperature limit for mechanical or electrical components is perhaps conservative by 50° C at most. The basis for this present 150° C limit temperature needs clarification, and present results suggest that the study should be continued.

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